TRANSMITTAL OF APPEAL BRIEF (Large Entity)			Docket No. 710240-23
In Re Application of: Warran B. Lineton			
Serial No. 10/643,097	Filing Date August 18, 2003	Examiner Sang W. An	Group Art Unit 1732
Title: METHOD OF FABRICATING PTFE MATERIAL			

OIPE IAP61 JUL 21 2006 PATENT & TRADEMARK OFFICE

TO THE COMMISSIONER FOR PATENTS:

Transmitted herewith is the Appeal Brief in this application, with respect to the Notice of Appeal filed on: May 23, 2006.

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☐ The Director has already been authorized to charge fees in this application to a Deposit Account.

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

APPLICANT:	Warran B. Lineton
SERIAL NO:	10/643,097
FILED:	August 18, 2003
FOR:	METHOD OF FABRICATING PTFE MATERIAL
EXAMINER:	Sang W. An

Board of Patent Appeals and Interferences
United States Patent and Trademark Office
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

July 21, 2006

S i r:

APPEAL BRIEF

This brief is submitted in support of the Notice of Appeal of the Final Rejection filed September 1, 2005.

(I) REAL PARTY IN INTEREST

This application is assigned to Federal-Mogul Worldwide, Inc which is wholly owned by Federal-Mogul Corporation.

(II) RELATED APPEALS AND INTERFERENCES

An appeal brief was filed on December 1, 2005, which received no action. The examiner withdrew the final rejection upon which the appeal brief was based and issued another non-final rejection dated February 23, 2006, thus, providing the issues in dispute for this appeal.

(III) STATUS OF CLAIMS

All claims 1-9 are presently rejected and on appeal.

CERTIFICATE OF MAILING

I hereby certify that this Brief for U.S. Serial No.: 10/643,097 filed August 18, 2003 is being deposited with the United States Postal Service as Express Mail Label No. ED 825862670 US, in an envelope addressed to Board of Patent Appeals and Interferences, United States Patent and Trademark Office, Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450 on July 21, 2006.

Karri M. Chamberlin

Karri M. Chamberlin

(IV) STATUS OF AMENDMENTS

An after-final response was filed on August 5, 2005 and was acted upon by the examiner in an advisory action dated August 24, 2005. The after-final response and the examiner's advisory action set forth opposing views with respect to the merits of the final rejection, and thus, an appeal brief was filed on December 1, 2005, which received no action. The examiner has since withdrawn the final rejection and issued another non-final rejection dated February 23, 2006, thus, providing the issues in dispute for this appeal.

(V) SUMMARY OF CLAIMED SUBJECT MATTER

This invention relates to a method of fabricating polytetrafluorethylene (PTFE) material. There are two independent claims drawn to the inventive method, namely claims 1 and 8, and dependent claims 2-7, and 9, respectively (Exhibit A shows all claims in their present, unmarked form).

Claim 1 calls for a mixture of PTFE resin powder and a susceptor material to be prepared. The mixture is fed into a compaction zone to at least partially compact and shape the mixture. A continuous flow of the mixture is fed from the compaction zone to a heating zone where the mixture is heated and sintered by exciting the susceptor material by application of wave energy.

Claim 2, which is dependant upon independent Claim 1, calls for drawing a vacuum on the mixture within the heating zone to extract air from the mixture.

Claim 8 calls for the preparation of a mixture of PTFE resin powder and a susceptor material. The mixture is compacted and then sintered by exciting the susceptor material with microwave energy.

Claim 9, which is dependant upon independent Claim 8, calls for drawing a vacuum on the mixture during the sintering to extract air from the mixture.

Referring to the Figures and specification, preparation of the mixture is discussed in paragraph 16 and is generally indicated at 12. Feeding the mixture into a compaction zone is discussed in paragraph 17 and is generally indicated at 14. Providing a continuous flow of the mixture from the compaction zone to a heating zone is discussed in paragraphs 18-20 and is generally indicated at 24. The heating and sintering by exciting the susceptor material via microwave energy is also discussed in paragraphs 18-20. The drawing of a vacuum is discussed in paragraph 19 and is generally indicated at 28.

(VI) GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL

1. Whether claims 1 and 5-8 are unpatentable as being anticipated under 35 USC

102(b) by Adams et. al.

2. Whether claims 1 and 5-8 are unpatentable as being obvious under 35 USC 103(a) over Adams et. al. in view of Encyclopedia of Polymer Science and Technology (vol. 5, pgs. 7-8).

3. Whether claims 2-4 and 9 are unpatentable as being obvious under 35 USC 103(a) over Adams et. al. in view of Eucker et. al..

4. Whether claims 2-4 and 9 are unpatentable as being obvious under 35 USC 103(a) over Adams et. al. in view of Encyclopedia of Polymer Science and Technology (vol. 5, pgs. 1-23) and further in view of Eucker et. al..

(VII) ARGUMENT

It is the appellant's position that the examiner has failed to establish a proper prima facia rejection of the appealed claims and that the rejections should be reversed by this Board.

Rejection of Claims 1 and 5-8 under 35 USC 102(a) over Adams et. al.

Claim 1

Claim 1, as summarized above in Section V, calls for the PTFE resin powder to be mixed with a susceptor material and then fed into a compaction zone to at least partially compact and shape the mixture after which the mixture is fed continuously from the compaction zone to a heating zone where the mixture is heated and sintered by exciting the susceptor material through application of wave energy.

The examiner cites Adams et al (Exhibit B) as anticipating claims 1, and 5-8, thereby requiring Adams et al to disclose all the aforementioned claimed steps. To reach the conclusion that Adams et al inherently teaches preparing a mixture of PTFE resin powder and a susceptor material, the examiner looks to the Encyclopedia of Polymer Science and Technology, (vol. 5, pgs. 7-8, Exhibit C), referred to hereafter as Encyclopedia, of which, pages 1-23 are incorporated by reference into Adams et al at Col. 4, lines 56-59. The examiner appears to go out on a tenuous, rather non-existent, limb to conclude that the Encyclopedia discloses the addition of high-loss material, such as carbon black, in low-loss material, such as PTFE, to increase the overall loss factor of the mixture and thereby make it suitable for dielectric heating. Upon close inspection of the Encyclopedia, it is applicant's position that this is not at all inherent, nor is it even suggested as being possible to reach the examiner's conclusion. To the contrary, the Encyclopedia states that it is not possible to dielectrically heat PTFE using current state of the art equipment (pg. 8, last sentence of the first full paragraph).

On pages 7-8 of the Encyclopedia, the only pages stated as being relevant during a phone conversation held on May 18, 2006 with the Examiner, Table 2 shows a listing of various materials with their associated "loss index" and corresponding "response to dielectric heating." It is noteworthy that of the materials listed, PTFE has <u>by far</u> the lowest "loss index", thus, making it the most <u>highly improbable</u> material listed to be dielectrically heated. It is also noteworthy to point out that the stated "loss index" of PTFE is 0.0004, and thus, is more than two orders of magnitude less than that disclosed as being "acceptable" in Adams et al. In Adams et al., starting at Column 4, line 14, it is disclosed that the starting material have a <u>sufficiently high</u> "loss factor", also being referred to as "loss index" in the Encyclopedia, to be effectively heated with dielectric heat. In preferred embodiments, the starting materials are selected from polymers or polymer compositions having loss factors <u>above</u> about 0.08, and preferably above 0.2. The examiner somehow reaches the conclusion that the Encyclopedia discloses PTFE as being able to attain this significantly increased level of loss factor? The Encyclopedia clearly shows ranges of relative ease of dielectric heating, wherein loss indexes of 0.2 or more result in good heatability; 0.08-0.2 as fairly good heatability; 0.01-0.08 as poor heatability; and under 0.01 as little or no response. It further shows that <u>PTFE has no response to dielectric heating</u>.

To overcome all of what is expressly stated in the Encyclopedia regarding PTFE and its inability to be heated dielectrically, the examiner looks to the second full paragraph on page 8 of the Encyclopedia. There, it states that techniques are available for heating <u>some</u> materials with low loss indexes. It further states that these materials show a rise in loss index high enough to make the material susceptible to dielectric heating. With this, the examiner selects the material having the lowest loss factor, PTFE, and leaps to the conclusion that it is one of the materials capable of achieving a rise in loss index sufficient enough to allow it to be dielectrically heated, and within the stated range of 0.08-0.2, or more preferably having a range above 0.2, as disclosed in Adams et al. Outside of arriving at this conclusion, the examiner does not provide any support or justification for making such a grand leap. As such, it is respectfully submitted that the examiner has misinterpreted the disclosure of Adams et al and the Encyclopedia, and thus has reached an improper ground for rejection of claim 1.

<u>Claims 5-7</u>

Claims 5-7 are ultimately dependant upon base claim 1, and thus, are believed to define patentable subject matter for at least the same reasons.

Claim 8

Claim 8, as summarized above in Section V, calls for the PTFE resin powder to be mixed with a susceptor material and then compacted and sintered by exciting the susceptor material through application of microwave energy.

There is no teaching or suggestion within the Adams et al reference to arrive at the claimed method of fabricating PTFE material as claimed in claim 8. Accordingly, for at least the same reasons stated above in support of claim 1, applicant believes that claim 8 defines patentable subject matter.

Accordingly, for at least these reasons, applicant respectfully request that this Board reverse the decision of the examiner with respect to the rejection of claims 1 and 5-8.

Rejection of Claims 1 and 5-8 under 35 USC 103(a) over Adams et. al. in view of Encyclopedia of Polymer Science and Technology (vol. 5, pgs. 7-8)

Claim 1

Claim 1 is stated above, and has been rejected as being unpatentable over Adams et al in view of the Encyclopedia. In this rejection, the examiner concedes that Adams et al does not explicitly disclose preparing a mixture of PTFE resin powder and susceptor material. As such, the examiner looks to the Encyclopedia to suggest that it discloses preparation of such a mixture. The examiner states that the Encyclopedia discloses addition of high-loss material such as carbon black in low-loss material such as PTFE in order to increase the overall loss factor of the mixture and thereby make it suitable for dielectric heating. As discussed above, applicant contends that this is a syllogism without merit. The only statement in the Encyclopedia is that some materials with low loss indexes show a rise in loss index high enough to make the material susceptible to dielectric heating. This certainly is not conclusive, let alone suggestive that the material having the lowest loss factor, PTFE, is one of these materials. To suggest otherwise is nothing short of flattery using improper hindsight of the applicant's disclosure.

Claims 5-7

Claims 5-7 are ultimately dependant upon base claim 1, and thus, are believed to define patentable subject matter for at least the same reasons.

Claim 8

There is no teaching, suggestion or motivation to arrive at applicant's claimed method of claim 8 in view of the Adams et al and/or the Encyclopedia reference, whether considered

separately or in combination with one another. To state that there is uses improper hindsight. Accordingly, for at least the same reasons stated above in support of claim 1, applicant believes that claim 8 defines patentable subject matter.

Accordingly, for at least these reasons, applicant respectfully contends that the examiner has failed to establish a prima facie case of obviousness, and thus, respectfully request that this Board reverse the decision of the examiner with respect to the rejection of claims 1 and 5-8.

Rejection of Claims 2-4 and 9 under 35 USC 103(a) over Adams et. al. in view of Eucker et. al.

Claims 2 and 9

Claims 2 and 9 depend from Claims 1 and 8, respectively, and further include drawing a vacuum on the mixture within the heating zone and sintering step, respectively, to extract air from the mixture. For the same reasons stated above in support of independent Claims 1 and 8, applicant contends that this rejection is improper. It is noteworthy that the examiner concedes that Adams et al fails to teach the step of drawing a vacuum on the mixture within the heating zone to extract air from the mixture. Therefore, to circumvent this lack of teaching, the examiner proposes to modify Adams et al with the teachings of Eucker et al (Exhibit D). To do so, the examiner directs our attention to column 2, lines 63-67 in Eucker et al. This attempt falls short in that there is no such teaching in this section, or any other section of Eucker et al to include a step of drawing a vacuum on a mixture while it is within the heating zone to extract air from the mixture, as taught by applicant. Rather, the disclosure of Eucker et al teaches drawing a vacuum during a billet forming step, and again thereafter during an extrusion step, as discussed in column 6, lines 1-7, and column 6, lines 40-47, and also as shown in Figures 1 and 21. The heating zone or sintering zone in Euker et al, identified by reference number 24, does not include a vacuum drawing step.

In addition to the failure to provide a teaching, suggestion or motivation to modify Adams et al to include a vacuum drawing step on the material within a heating or during a sintering step, the examiner fails to consider what affect a vacuum could have on the ability of the process taught by Adams to produce a material that is porous, as stated in the title and throughout Adams et al. It seems that a vacuum could cause the voids in the material, deemed as desirous in Adams et al, to collapse or at least have a negative effect on developing porosity. If so, it would seem reasonable that one skilled in the art would be lead away from using a vacuum within the heating zone or during the sintering step, as taught by

applicant.

Claims 3 and 4

Claims 3 and 4 are ultimately dependant upon base claim 1, and thus, are believed to define patentable subject matter for at least the same reasons.

Accordingly, for at least these reasons, applicant respectfully suggests that the examiner has failed to establish a prima facie case of obviousness, and thus, respectfully request that this Board reverse the decision of the examiner with respect to the rejection of claims 2-4 and 9.

(VIII) CLAIMS APPENDIX

See Exhibit A.

(IX) EVIDENCE APPENDIX

None.

(X) RELATED PROCEEDINGS APPENDIX

None.

(XI) CITED REFERENCES APPENDIX

Claims (Exhibit A)

Adams et al (Exhibit B)

Encyclopedia of Polymer Science and Technology, Vol. 5 (Exhibit C)

Eucker et al (Exhibit D)

It is believed that all claims on appeal clearly are allowable over the prior art of record. Accordingly, reversal of the final rejection and the allowance of all claims on appeal are requested.

Respectfully submitted,
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By his attorney,

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1. A method of fabricating PTFE material comprising:

preparing a mixture of PTFE resin powder and a susceptor material;

feeding the mixture into a compaction zone to at least partially compact and shape the mixture; and

providing a continuous flow of the mixture from the compaction zone to a heating zone and heating and sintering the mixture within the heating zone by exciting the susceptor material by application of wave energy.

2. The method of claim 1 including drawing a vacuum on the mixture within the heating zone to extract air from the mixture.

3. The method of claim 2 wherein the heating zone has an initial stage for preheating and finishing compaction of the mixture prior to sintering the mixture.

4. The method of claim 2 including passing the sintered mixture through a cooling zone following the heating zone.

5. The method of claim 1 including cutting the PTFE material while the mixture is at a temperature below a sintering temperature within the heating zone but above ambient temperature.

6. The method of claim 1 wherein the mixture is compacted into a generally tubular form.

7. The method of claim 1 wherein the mixture is heated by microwave energy.

8. A method of fabricating a PTFE material, comprising:

preparing a mixture of PTFE resin powder and a susceptor material;

compacting the mixture; and

sintering the mixture by exciting the susceptor material with microwave energy.

9. The method of claim 8 including drawing a vacuum on the mixture during the sintering step to extract air from the mixture.

ENCYCLOPEDIA OF POLYMER SCIENCE AND TECHNOLOGY

Plastics, Resins, Rubbers, Fibers

VOLUME 5

Dielectric Heating to Emulsion

Pub. 1966.

Library of Congress Catalog Card Number: 64-22188

Printed in the United States of America

D continued

DIAZOALKANES. See POLYALKYLIDENES

DICARBOXYLIC ACIDS AND DERIVATIVES. See ACIDS, MALEIC AND FUMARIC; ACIDS AND DERIVATIVES, ALIPHATIC; ACIDS AND DERIVATIVES, AROMATIC

DICHROISM. See OPTICAL ROTATORY DISPERSION

DICUMYL PEROXIDE. See PEROXY COMPOUNDS

DIELECTRIC HEATING

Electric currents, radio waves, infrared rays, and light are familiar examples of different electromagnetic phenomena. When electromagnetic energy comes in contact with matter (solid, liquid, or gas), it is partly or completely converted to heat energy: for example, an electric current may heat the wire through which it flows; infrared radiation may be used to cook food or bake paint; and laser beams may melt holes in metals. Electromagnetic energy at radio-frequencies can be used efficiently to heat many materials, including some which conduct electric currents very poorly or not at all.

The latter are of the class of materials called dielectrics; the heating process is termed *dielectric heating*. More generally, a dielectric material may be defined as one in which it is possible to store electrical energy by the application of an electric field; the energy is recoverable when the field is removed (see also ELECTRICAL PROPERTIES). Dielectric materials are usually very poor heat conductors. To heat such substances throughout their volume is very difficult with processes that apply the heat to the surface only. Electromagnetic energy in the radio-frequency (RF) range, on the other hand, can act below the surface of a dielectric material and heat *all* parts of the volume simultaneously, with substantially greater speed and uniformity of heating than with conventional methods. Other advantages of dielectric heating are that it can be turned on and off instantaneously; it is efficient and thus does not throw off a great deal of wasted heat; it can be precisely and accurately controlled with reasonably simple devices; it can heat selected sections of a part, leaving the remaining material cool. Dielectric heating equipment is easy to operate, is basically long-lived, and requires little maintenance.

Dielectric heating was used as early as 1880 by a physician, Dr. W. J. Morton (1), but its significance was first reported by d'Arsonval in 1890 and Tesla in 1891. By

1900, it was in practical use by doctors (who later named it *diathermy*) for treating parts of a patient's body well below the skin surface, with highly beneficial effects. Substantial industrial use did not start until World War II. Techniques were needed and quickly developed for setting resin glues in wood products, for preheating thermosetting plastics for molding; for welding vinyl materials, and for welding glass pipe (see WELDING) (2). After the war, its use increased rapidly in many fields. Dielectric heating is employed when simple heating is required, as in water removal from wood products (3), textiles, and foam rubber; freeze drying of food (4,5); thawing of frozen foods (6); and softening plastic materials for forming. It provides heat for chemical reactions: preheating thermosetting compounds for molding (7); setting resins impregnated in paper products (8); curing vinyl and polyurethan foam; curing resin glue in wood and paper products; and starting exothermic reactions in thermosetting resins being extruded continuously. It is also used in combination with mechanical processes for forming or welding plastics and plastic-impregnated or coated materials.

For dielectric heating, two ranges of radio-frequencies are used: For most processes, a frequency somewhere in the 1–200 megacycles per second (Mc/sec) range, usually called *high-frequency* or *radio-frequency heating;* for a small but increasing amount of work, frequencies above 890 Mc/sec, called *microwave heating*. The fundamental relationship for electromagnetic waves,

$$\text{frequency (Mc/sec)} \times 10^6 \times \text{wavelength (m)} = 3 \times 10^8 \text{ (velocity of light)} \quad (1)$$

indicates decreasing wavelength for increasing frequency. The wavelength for 30 Mc/sec is 10 m, commonly used for "high-frequency" heating. The wavelength for 1000 Mc/sec is 0.1 m, which is considered short for a radio wave, and is therefore called a "microwave."

In high-frequency heating, the material to be heated is usually placed between two electrodes. When high-frequency energy is applied to the electrodes, the material between the electrodes is heated fairly uniformly throughout its volume. In microwave heating, the energy is applied by *horns* or *waveguides*, and its effect decreases to a negligibly low value at some point below the surface, the depth of the penetration depending on the frequency and on the material being heated.

Theory

Dielectric heating, at any frequency, is the result of the interaction of electromagnetic energy with the various components in the atomic and molecular structure. An alternating electric field causes oscillatory displacements in the charged components of the dielectric, the energy for the motion being absorbed from the electric field. The charges carried by the oscillating components may be either permanent or induced. Each component resonates with the electrical field at a particular frequency that depends on its charge, mass, and structure. In gases and some liquids, this resonance phenomenon occurs at sharply defined frequencies, but in most solids it is spread over a broad range. All charged components undergo some oscillatory displacement at low frequencies, the motion becoming much greater at the resonance frequency or frequency range, and ceasing above it. In the ranges of resonance frequencies, considerably greater heating takes place than outside these regions.

In macroscopic terms, the dielectric material behaves in the following manner. When an alternating voltage is applied to a dielectric, a current (called a *displacement*

current) flows through it, causing energy to be stored in the dielectric. The amount of current flowing, and the amount of energy stored, depend on the voltage, the frequency, the electrode configuration, and the chemical and physical structures of the dielectric material. The chemical structure determines to a large extent the *dielectric constant*, ϵ', of the material, a property defined as the ratio of the capacitance of a material in a given electrode configuration to the capacitance of the same electrode configuration with a vacuum as the dielectric. Its value for any material decreases with increasing frequency, showing decreasing response to the electric field.

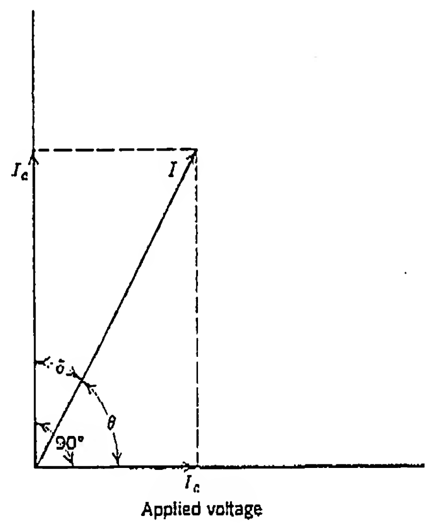


Fig. 1. Representation of current components in an imperfect dielectric. I represents displacement current; I_c, charging current; I_e, effective heating current; δ, loss angle; θ, phase angle.

In the case of a perfect, or lossless, dielectric, the displacement current leads the voltage by a temporal *phase angle*, θ, of 90°. For an imperfect, or "lossy," dielectric, the phase angle is less than 90°. The angle by which it differs from 90° is called δ, the *loss angle;* its tangent, tan δ, called the *loss tangent*, or *dissipation factor*, indicates directly the fraction of the stored energy which is converted into heat by the dielectric. The cosine of the phase angle θ is known as the *power factor*, and its value is approximately the same as that of the loss tangent for small loss angles, such as are characteristic of the usual materials heated dielectrically.

For calculations involving dielectrics, the displacement current can be resolved into two components, the *charging current* I_c, and the *effective heating current* I_e. I_c leads the applied voltage by 90°, and I_e is in phase with the applied voltage (Fig. 1). The ratio I_e/I_c represents the loss tangent, or dissipation factor, tan δ. The charging and the effective heating currents may be visualized as flowing in the branches of a simple circuit consisting of a "perfect" capacitor in parallel with a pure resistor (Fig. 2).

In the simplest form of dielectric heating, the material to be heated is placed between two metal plates. A generator applies to the plates a high-frequency voltage that sets up an electric field in and around the material. The material absorbs energy at a rate given by equation 2 (9),

$$P = 0.555 f E^2 \epsilon' \tan \delta \times 10^{-6} \qquad (2)$$

where P = heat generated in watts/cc (dielectric loss), f = frequency in Mc/sec, E = field strength in V/cm, ϵ' = dielectric constant, and $\tan \delta$ = loss tangent. This formula shows that the heating effect is directly proportional to the frequency, directly proportional to the square of the applied voltage, and directly proportional to the dielectric constant and the loss tangent. In most applications, the dielectric constant and the loss tangent are fairly constant over the dielectric heating frequency range, at a fixed temperature. Therefore, a "best frequency" need not be sought for; the desired heating rate is obtained by selecting a frequency range and voltage for which it is practicable to build equipment and for which a suitable electrode system can be designed.

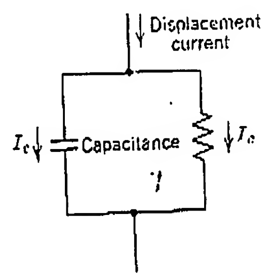


Fig. 2. Simple circuit equivalent of a dielectric.

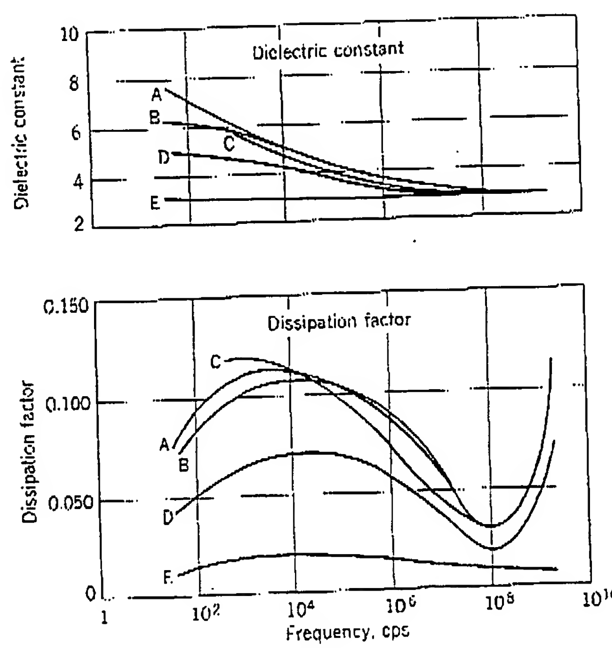


Fig. 3. Effect of frequency of applied voltage on the electrical properties of commercial vinyl resins measured at room temperature: (A) Geon 2046, B. F. Goodrich Chemical Co.; (B) Koroseal 5CS-243, Goodrich; (C) Vinylite VG 5901, Union Carbide Corp.; (D) Saran B 115, Dow Chemical Co.; (E) Vinylite QYNA, Union Carbide (11).

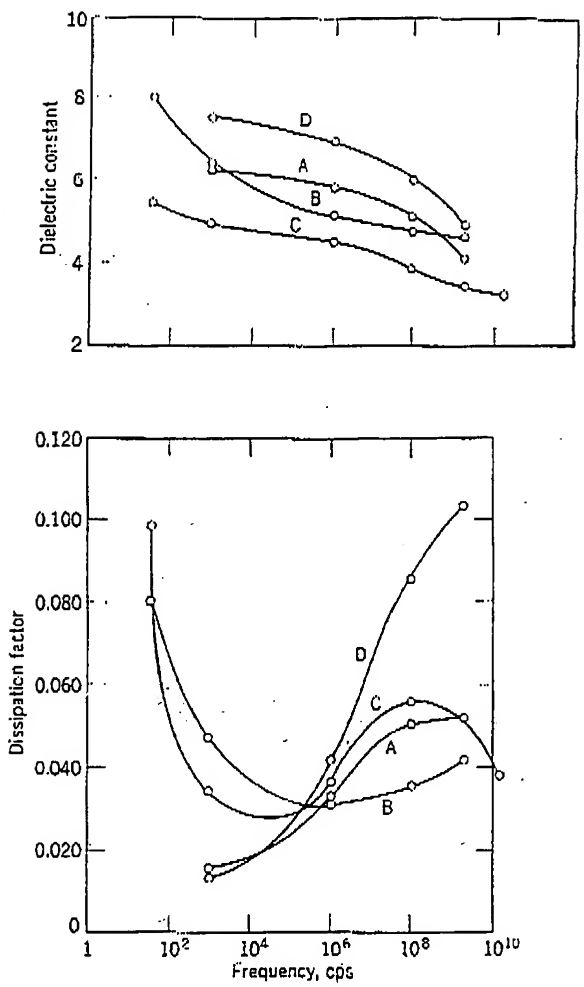


Fig. 4. Effect of voltage frequency on electrical properties of formaldehyde resins: (A) melamine formaldehyde resin, wood-flour filled and plasticized; (B) melamine–formaldehyde resin with mineral filler; (C) cresol formaldehyde resin with α-cellulose filler; (D) melamine formaldehyde resin with α-cellulose filler (11).

The maximum value of voltage that can be used is limited by the voltage breakdown characteristics of the material, by its surroundings, and by electrode construction. Breakdown may occur inside the material, or in the space between the electrodes outside the material, damaging or destroying the material and melting holes in the electrodes. The breakdown is usually an arc of electrons or ions which concentrates the power of the high-frequency generator into a path of very small cross section. Arcing problems are reduced by careful electrode design and construction: The electrodes should be designed so that as much as possible of the voltage applied to the electrodes is developed in the material being heated, and they should be made with rounded edges and corners wherever possible because sharp edges and points concentrate the voltage stresses and are the first places breakdown occurs. It would appear

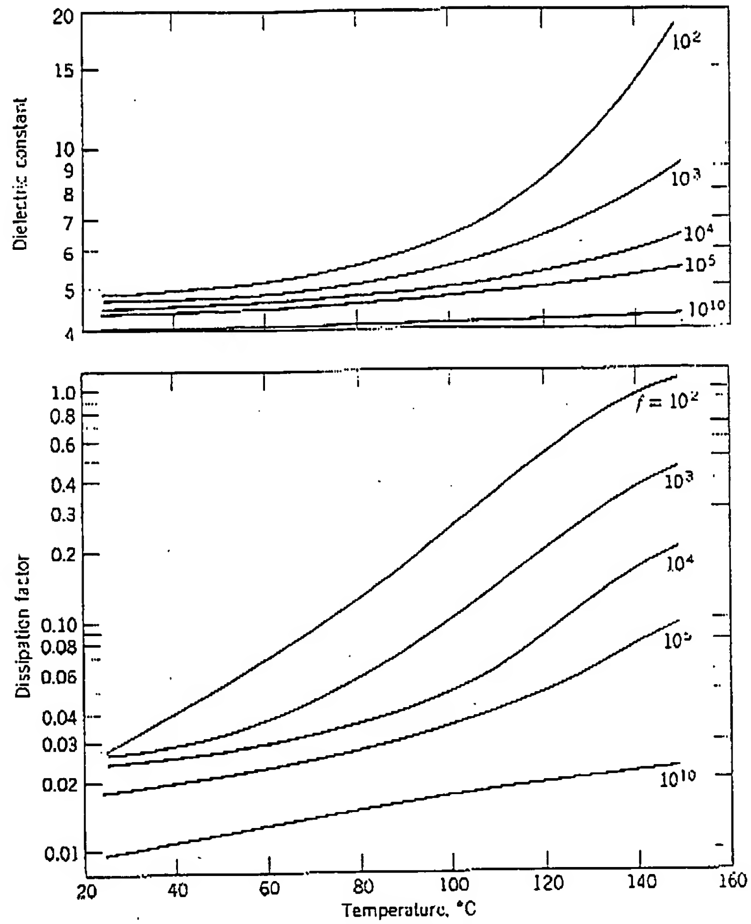


Fig. 5. Effect of temperature on dielectric constant and dissipation factor of phenol-formaldehyde resins (Resinox 10900, Monsanto) (Ref. 10, p. 409).

Table 1. Typical Dielectric Constants and Loss Tangents of Several Materials[a]

Material		Frequency, Mc/sec			
		1	10	100	3000
phenol-formaldehyde resin, 57°C	ϵ'	4.9	4.65	4.5	4.15
	$\tan\delta$	0.043	0.047	0.048	0.053
polyamide (nylon-6,6), 25°C	ϵ'	3.33	3.24	3.16	3.03
	$\tan\delta$	0.026	0.024	0.021	0.013
polyester, 25°C	ϵ'	3.11	3.04	2.98	2.85
	$\tan\delta$	0.0130	0.0160	0.0160	0.0100
polytetrafluoroethylene, 22°C	ϵ'	2.1	2.1	2.1	2.1
	$\tan\delta$	........less than 0.0002........			0.00015
ice, −12°C	ϵ'	4.15	3.7		3.2
	$\tan\delta$	0.12	0.018		0.0009
water, 25°C	ϵ'	78.2	78.2	78.0	76.7
	$\tan\delta$	0.040	0.0046	0.0050	0.1570

[a] Values derived from von Hippel.

that the frequency used should be as high as possible so that the lowest voltage can be employed, but there are limitations with this too. At higher frequencies the generating equipment is more costly, and it is increasingly difficult to deliver the power from the generator to the material with good efficiency and control. It also becomes increasingly difficult to maintain uniform voltage distribution over the entire mass of the material.

The ease with which any material may be dielectrically heated is determined by its dielectric constant and its loss tangent. Values of these factors for several typical materials are given in Table 1 (10), for different frequencies. Notice that ϵ' falls with rising frequency, except for polytetrafluoroethylene; the sharper the drop, the higher will be the loss tangent. Coincident with the higher loss tangent shown for water at 3000 Mc/sec, there is a sharp decrease in the dielectric constant, not shown in the table. Polytetrafluoroethylene shows no change in ϵ', and the loss tangent is, as anticipated, exceptionally low. Changes in dielectric constant and dissipation factor over ranges of frequency and temperature are shown in Figures 3–5 for some other materials.

The product, $\epsilon' \times \tan \delta$, also called the *loss index* (or *loss factor*), ϵ'', shows most conveniently the combined effect of the two factors. Table 2 lists this product for many materials, and indicates the relative ease of heating. Loss indexes of 0.2 or

Table 2. Relative Response of Various Materials to Dielectric Heating[a]

Material	Typical loss index	Response			
		Good	Fair	Poor	None
ABS polymers	0.025		*	×	
acetal copolymer	0.025		*	×	
cellulose acetate	0.15		×		
diallyl phthalate polymer, glass-filled	0.04		*	×	
epoxy resins	0.12		×		
melamine–formaldehyde resin, cellulose filler	0.2	×			
phenol–formaldehyde resin, wood-flour filler	0.2	×			
polyamide	0.16		×		
polycarbonate	0.03		*	×	
polychlorotrifluoroethylene	0.025			×	
polyester	0.05		*	×	
polyethylene	0.0008				×
polyimide	0.013			×	
poly(methyl methacrylate)	0.09		×		
polypropylene	0.001				×
polystyrene	0.001				×
polytetrafluoroethylene (Teflon)	0.0004				×
polyurethan foam				×	
polyurethan–vinyl film		×			
poly(vinyl chloride), flexible, filled	0.4	×			
rubber, compounded	0.13		×		
rubber, hevea	0.015			×	
silicones	0.009			*	×
urea–formaldehyde resin	0.2	×			
water	0.4	×			

[a]Information derived from references 12 and 13 and from the dielectric heating experience of the author; (×) heatability in the 20 to 30 Mc/sec range; (*) response of the materials in the 70 to 100 Mc/sec range.

more result in good heatability; 0.08-0.2, fairly good heatability; 0.01-0.08, poor heatability; and under 0.01 there is little or no response. The lower the loss index the higher must be the voltage and frequency to obtain the required heating rate; for a material with a very low loss index, the required heating voltage at economically attainable frequencies is higher than the breakdown voltage.

Two calculations using equation 2 should demonstrate this. A typical application, to weld two square inches of two 0.005-in. thick films of poly(vinyl chloride) (flexible, filled), requires about 1000 W, which is 3050 W/cc. A reasonable voltage to use is 500 V across the double thickness of film, or 19,700 V/cm. By using a loss index of 0.4, from Table 2, the frequency is computed to be 35.4 Mc/sec. Equipment is readily available to deliver this voltage and frequency. For the same power input to a polytetrafluoroethylene load of the same size, the frequency required is 35,400 Mc/sec, because the loss index of polytetrafluoroethylene is 0.0004. Since equipment at this frequency is beyond the current state of the art, polytetrafluoroethylene may therefore not be dielectrically heated at present.

There are, however, techniques available for heating some materials with low loss indexes. Many of these materials show a rise in loss index with rising temperature. With auxiliary heating means—radiant heat, hot air, or electrically heated platens—the temperature can be raised to the point at which the loss index is high enough to make the material susceptible to dielectric heating. A similar result may be achieved by placing a high-loss material in contact with the low-loss material; the high-loss material heats and transfers its heat to the low-loss load. Another approach is to mix additives or fillers with the low-loss material to raise the loss factor to a suitable level. Some examples of such additives are carbon black in rubber, sodium chloride in urea-formaldehyde glues for wood, and poly(vinyl chloride) in polyurethan foam—this last not only increases the susceptibility of the foam to dielectric heating but makes it more readily bondable to poly(vinyl chloride) sheet. Since the filler may affect the chemical, physical, or other properties of the base material, the type and the amount added are limited by the changes that can be tolerated.

Equipment

High-frequency and microwave heating equipment usually has five major sections: the power supply, the high-frequency generating system, the high-frequency transmission system, the control system, and the work applicator fixtures. The sections may be contained in one or more cabinets, depending on the application. The power supply section usually contains transformers, rectifiers, and switch-gear, which convert the usual powerline energy (eg, 440 V, 3-phase, 60 cycles) to high-voltage dc energy, at 1,000-20,000 V. The high-voltage dc is fed to the high-frequency, or oscillator, section, which usually consists of a single high-power electronic tube (vacuum triode, tetrode, etc), with associated high-frequency circuits. In microwave equipment, the generating circuits are usually an integral part of the tube, called a magnetron; sometimes a klystron tube is used, with external circuits, or "cavities." The high-frequency voltages are actually generated in a capacitor-inductor combination. Energy is stored alternately in the capacitor and in the inductor—in the capacitor in an electric field, and in the inductor in the magnetic field of the current flowing in the inductor. Current flowing in the inductor charges the capacitor to one polarity; when it is fully charged the current stops flowing and then begins flowing in the opposite direction through the inductor to charge the capacitor fully in the opposite

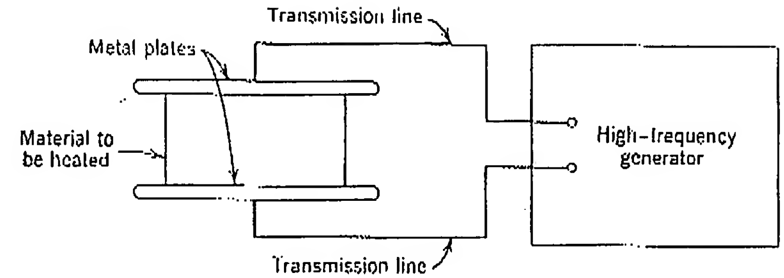
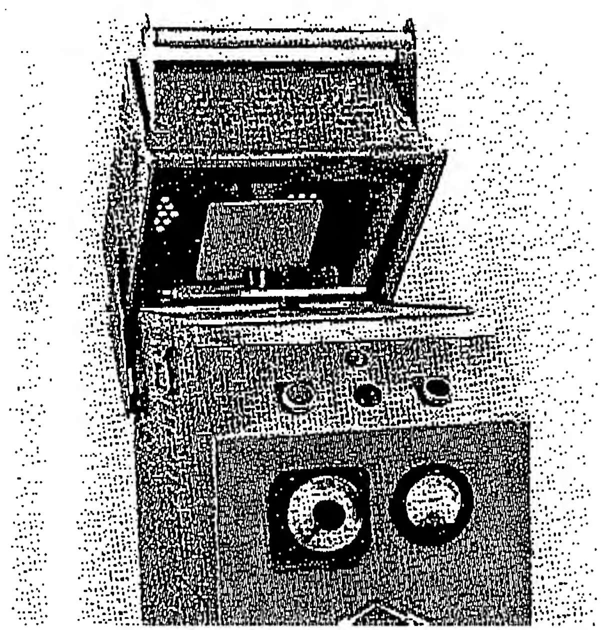


Fig. 6. Schematic representation of elements of a simple dielectric heating system.

direction. The vacuum tube acts as a switch between the power supply and this inductor capacitor combination, switching current from the power supply at the appropriate times required by the capacitor-inductor combination.

The high-frequency voltage, up to tens of thousands of volts, is delivered through a transmission line to the work applicator fixture. These fixtures have many variations, of which the arrangement shown in Figure 6 is the simplest. Figure 7 is a picture of a small plastic preheater, which uses the arrangement of Figure 6, showing two plastic preforms on the lower electrode; the upper electrode is tilted backward for access. The upper electrode and hood are lowered and closed for the heating cycle. Figure 8 has similarly arranged plates, but opened up to give a gap above the material



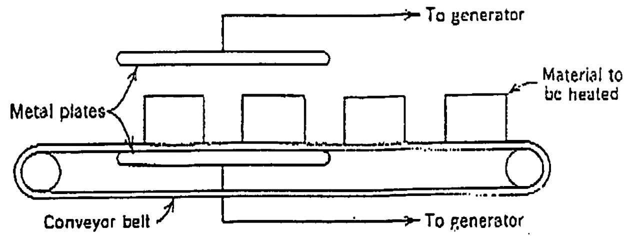


Fig. 8. Dielectric heating system with conveyor belt.

being heated; the power level can be adjusted by changing the height of this gap. It also shows a conveyor that can be used to carry materials between the plates on a continuous or intermittent basis. The conveyor belt must be made of a material that will not react with the load or be affected deleteriously by the electrode field or heat. The belt might be a low-loss material such as silicone rubber, or glass fiber, or it might be a good conductor such as stainless steel.

The control section turns the power on and off; it may be used to set components in the other sections to adjust the power level to the requirements of the process. Meters are usually provided to indicate the electrical performance of the power tube. Protective relays are incorporated where needed to turn the machine off in the case of component failure or overheating, or other improper operation. For process control, direct temperature measurements by conventional thermocouple techniques are not used because the thermocouple seriously distorts the heating pattern. Instead, the heating rate is sensed indirectly, but quite accurately, by a dc meter indicating the power supply current, or by electrode voltage measurement, or both. In batch processes the total heat input is controlled by setting the power controls and turning the power on for a fixed time interval. Automatic controls are available to adjust the power level to a programed set of current or voltage values.

Although direct temperature measurement is not usually feasible, properties of the material (which change with the temperature) may be monitored for process control. For example, the dc resistance of the heating material can easily be measured; the resistance may vary widely with changing temperature, and so may be used to regulate the power level for temperature control. The resistance level usually drops precipitately just before electrical breakdown (arc-over) occurs, and is very low after arc-over.

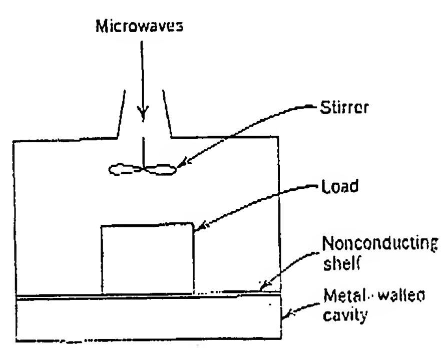


Fig. 9. Schematic representation of microwave heating system.

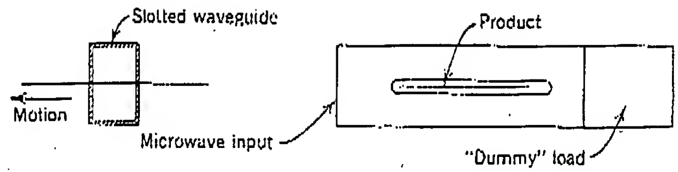


Fig. 10. Arrangement for dielectric heating with microwaves using waveguides.

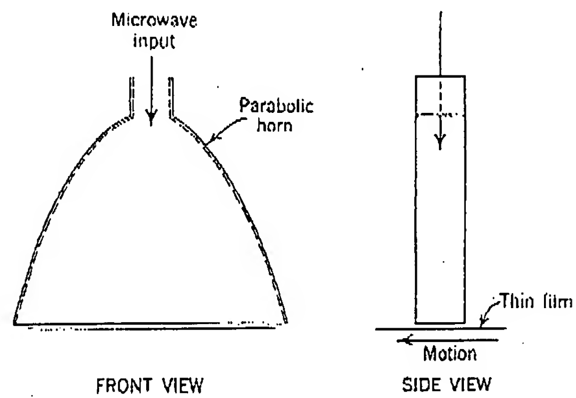


Fig. 11. Parabolic waveguide for heating with microwaves.

Detection circuits are available to sense this change and to turn off the high-frequency power with such rapidity that the electrodes will be virtually unmarked (although the load itself may be damaged). Other devices that measure the proximity of the work to an arcing condition can limit the occurrence of arcs. This is a necessity where the electrodes are expensively machined members which must provide very precise mechanical pressures to the load. Another method of protection against arc-over makes use of the "radio noise" generated by an arc. A "noise" detector probe is placed near, but not necessarily in physical contact with, the electrodes and material; the probe circuits will turn off the power when arc-over occurs.

Although its power supply and control sections are similar to those of high-frequency generators, microwave equipment appears simpler because no high-frequency circuits are apparent. The microwaves are generated within the magnetron tube structure, aided by an external magnet. From the magnetron, power is fed to the applicator. For bulk processing, a horn arrangement "sprays" the waves into a cavity that holds the load. The cavity is an integral part of the electrical circuit and its design must take into account the frequency and load characteristics. Energy not absorbed immediately by the load is reflected to the load by the metal walls, improving the heat distribution. Figure 9 shows this arrangement schematically. The non-conducting shelf above the bottom allows some energy to be reflected to the underside of the load. The energy distribution in the cavity is not uniform and is referred to as a *standing field*. A slowly rotating fan or "stirrer" also helps heat the load more evenly. Microwaves can be transmitted through hollow round or rectangular pipes called "waveguides." Products can be heated by placing them in the waveguides. Thin films can be run through the waveguides by slotting as in Figure 10. The magnetron will burn out if the equipment is operated without a load; a safety device is

therefore required—it is usually a "dummy" load (shown schematically in Figure 10) arranged to absorb some power when the normal load is absent. By running a film through several waveguides in succession, reasonable efficiencies can be attained. A waveguide can be terminated in a parabolic horn to spread the energy over a wider area, for heating thin film or bulk products (Fig. 11).

For many applications, standardized equipment is available as complete processing packages. Some applications are so specialized that equipment must be specially designed—the equipment manufacturer may build the entire machine, or he may furnish the generator, which the user will then connect to an electrode system of his own construction. High-frequency generators are available in a wide range of output

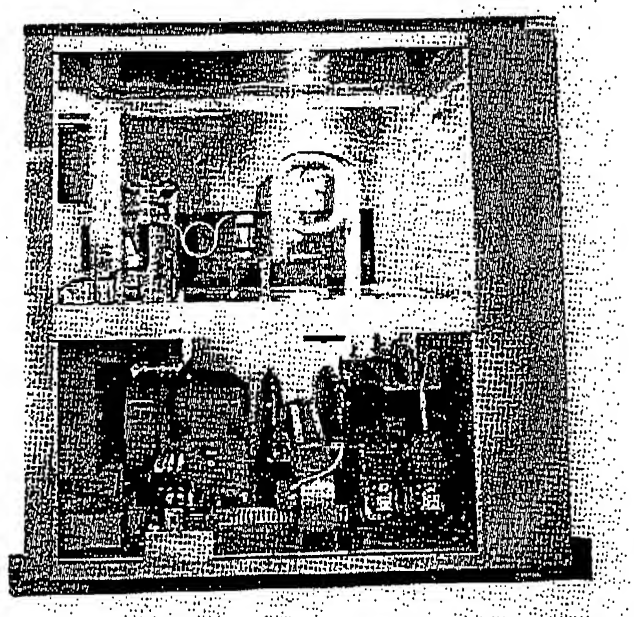


Fig. 12. A 40-kW generator. *Upper half* is high-frequency generating section; at right, copper tubing inductor. *Lower half* is power supply; right half is power transformer and rectifier; at left, blower for forced-air cooling of power tube. Courtesy Faratron.

power ratings, from about 50 W up to many hundreds of kilowatts. Up to 2 or 3 kW can be obtained at up to 200 or 300 Mc/sec; 25 kW at 100 Mc/sec and 100 kW at 30 40 Mc/sec are also available, although the operating frequency is usually lower for these and for higher powered units. Microwave generators can be had at 900 or 2500 Mc/sec, with outputs up to 25 kW. For continuous-flow processing, generators and electrode systems can be set alongside each other to meet larger power requirements. However, it is extremely difficult to make more than one generator operate on one electrode system. Batch processes therefore require a single generator of large enough capacity to supply the entire heat requirement. Figure 12 shows the inside of a 40-kW generator.

Applications

Preheating. The simplest application of dielectric heating is for preheating materials for compression or transfer molding; preheating is not only desirable but necessary in some cases (see MOLDING). Preforms or powders of phenolic, urea, melamine, or alkyd resins, polyesters (including glass fiber-reinforced materials), allyl polymers, and others are heated to about 250 to 325°F, in 15 to 60 sec. The rapid, thorough heating reduces mold pressure requirements by at least 50% and cuts cycle times 15 to 85% below the values needed when no preheating is used. Substantially higher product quality frequently results; rejects are fewer and mold life is increased (7).

Preheaters operate in the 20–100 Mc/sec range, present practice leaning toward the top end of this range for greater heating speed, especially for lower-loss materials. They are available in many sizes, as manually loaded units (Fig. 7), or with mechanized material-loading equipment for automatic operation (Fig. 13). Power output requirements are figured at 1 kW to heat one-third to two-thirds of a pound of material to molding temperature in 1 min. Preheaters are also used for moisture removal from plastic and wood products; a typical large special-purpose equipment is shown in Figure 14. For such applications power requirements can be estimated closely by standard thermal calculations, taking into account such factors as specific heat, heat of vaporization, and heat losses. Use of a preheater for defrosting large rubber bales is shown in Figure 15.

Dielectric preheaters are now being used in casting (qv), potting, and curing of epoxy resins, polyesters, polyurethans, and vinyl plastisols (see VINYL DISPERSIONS). In a typical process, an epoxy resin–hardener system for casting is heated in about 30 sec from room temperature to just below its curing temperature, and then poured into a heated steel mold. The filled mold is then heated for 30 min in a conventional oven, which gels the casting sufficiently to permit removal from the mold for postcure.

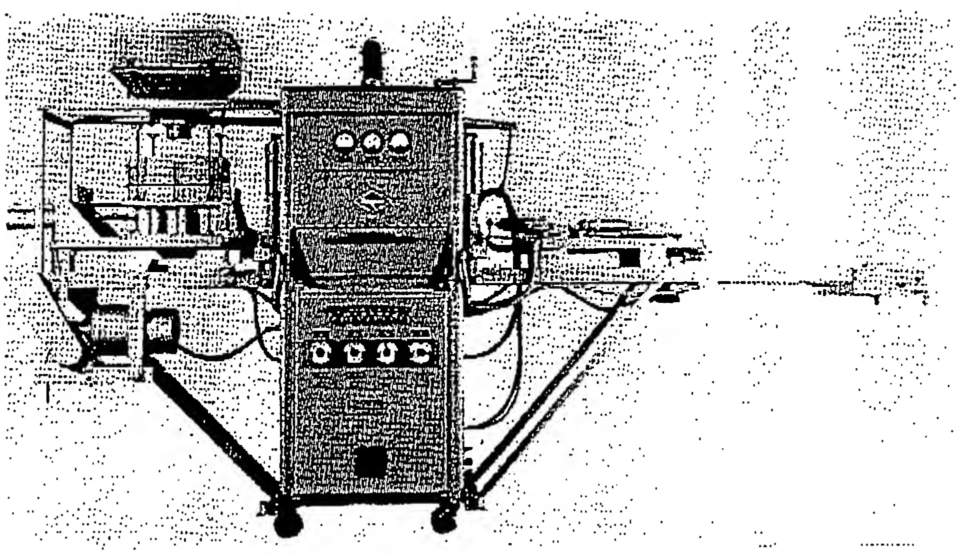


Fig. 13. Preheater equipped with hopper and feed mechanism and with 7.5-kW output for automatic heating of powdered materials. Courtesy W. T. LaRose & Associates, Inc.

Because the time the mold would remain in the oven without dielectric preheating is about 1.5 to 2 hr, preheating results in greatly increased productivity for the mold, which may be complicated and costly. Other benefits of this process are more uniform

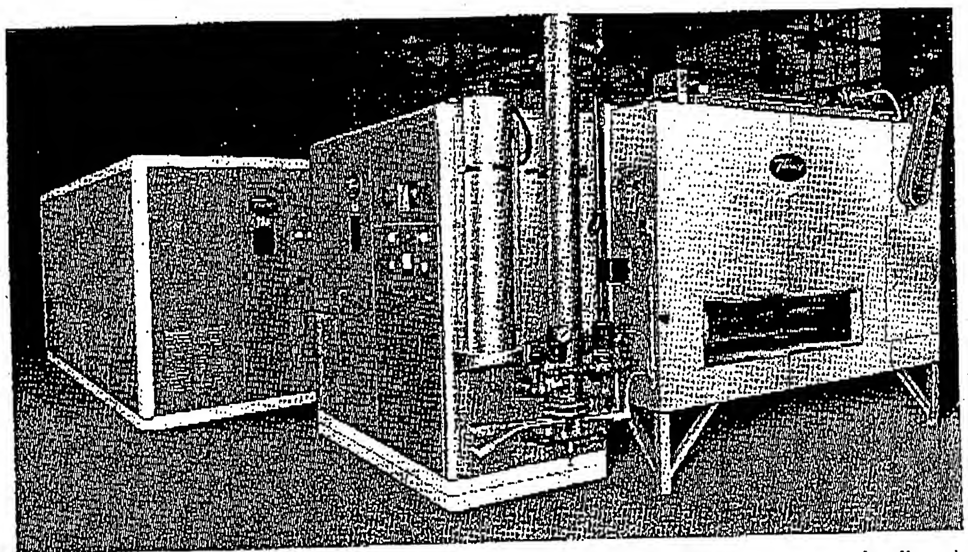


Fig. 14. Unit for preheating stacks of fiberboard panels prior to pressing into hardboard. Equipment is rated at 200-kW output continuous duty. Electrode system, in compartment on right, is a low-pressure press with 5 × 10 ft platens. Heating cycle of about 2 min is required to dry to zero moisture and preheat to 325°F. Courtesy Votator Division, Chemetron Corporation.

Fig. 15. Dielectric heating equipment with 30-kW output being used for defrosting 250-lb rubber bales prior to processing. Courtesy W. T. LaRose & Associates, Inc.

heating, greater freedom from air bubbles, fewer thermal degradation problems, and less restriction on mold design (14).

Foam Curing. An arrangement for curing of vinyl foam by dielectric heat is sketched in Figure 16. Unfoamed vinyl compound is poured into a 4 × 8 ft tray consisting of an aluminum base with silicone–glass fiber-laminate sides. (This is a rigid low-electrical-loss dielectric material, needed to contain the foam without distorting the high-frequency field, and without itself being deleteriously affected by the field or the thermal conditions in the oven.) Several of the trays are stacked in an oven, each tray under its own electrode. Because the liquid vinyl resin is only a fraction of an inch thick, it cannot be heated efficiently with the electrodes spaced for the full-foamed thickness of about 6 or 8 in. However, it is thin enough to be heated rather uniformly by the gas-heated hot air that is circulated around the trays. The hot air provides sufficient heat for complete foaming of the liquid, but this heat is totally inadequate to cure the full thickness of the foam in any reasonable time without serious degradation of the outside of the slab. Dielectric heating provides the ideal solution to this problem. While the hot air circulation is maintained around the trays, the dielectric heater is turned on for about 10–20 min, giving an extremely uniform cure throughout the 8-in. slab. Dielectric heating could also be used in the foaming stage. The electrode would be placed close to the surface of the unfoamed material,

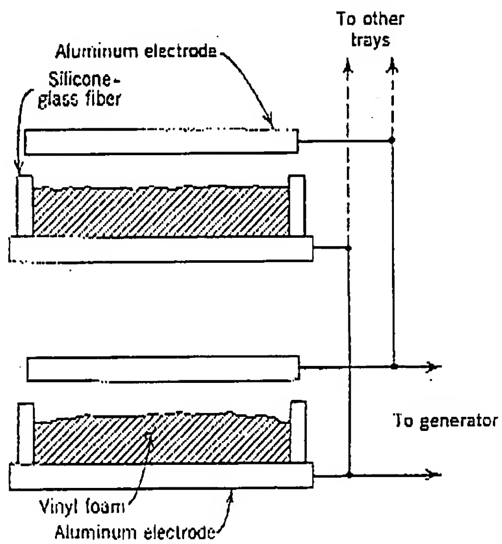


Fig. 16. Arrangement for curing vinyl foam by dielectric heat.

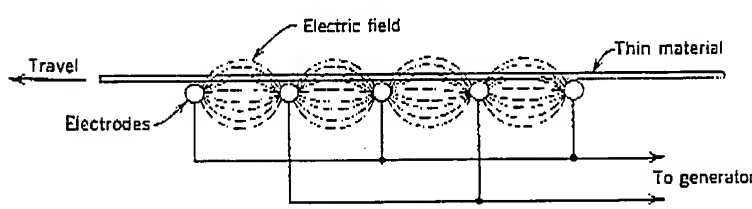


Fig. 17. Arrangement for drying thin material by dielectric heat.

and moved up as foaming progresses. The voltage might be varied simultaneously for quickest heating. See also CELLULAR MATERIALS.

Drying. In drying applications, uniformity of dielectric heating is less critical. This is because water has a far higher dissipation factor than the usual material being dried. As the wet material is heated, the water evaporates and the rate of energy absorption in the dried areas drops drastically. The wet spots continue to absorb energy at a high rate. The material will usually dry quite thoroughly throughout its volume before the temperature of any of the drier parts rises considerably above the boiling point. For bulk drying, dielectric heating has great speed and uniformity, but it is also useful for thin materials. Figure 17 shows an arrangement for heating a thin web of material that has been in use since 1960 for drying photographic paper after development and rinsing. The electrodes consist of parallel rods of metal, such as stainless steel, which are connected to alternate terminals of the generator. The dashed lines indicate how the electric field is set up between the electrodes, causing what is generally called *stray-field heating*, because the material heated is not directly between the electrodes. The heating pattern is uneven; the web must be moved for best heat distribution. Although the surface closest to the electrodes dries first, the entire paper is dry in less than 10 sec. This system is now being tested in papermaking as a possible replacement for drum dryers. Experiments with a 30-kW unit have been so successful that two 150-kW generators are being constructed for operation in regular production. Dielectric drying produces higher quality paper in several respects: more even moisture distribution, better surface finish, and improved mechanical qualities. The dielectric dryer requires far less space than conventional equipment of equivalent production capacity (15,16). In place of the paper, a thin Teflon glass fiber belt can be used to carry objects to be treated; the electric field acts through the belt with little diminution. This arrangement is being used to set poly(vinyl acetate) glue on the backs of books placed glued surface down on the belt. See also DRYING.

Wood Gluing. Figure 18 shows another stray-field application, in which a panel of wood is glued to a wood block. The loss index of the resin is such that most of the heat is developed in the glue and very little in the wood, even though the glue line is somewhat removed from the electrodes and the voltage on the wood is slightly higher than on the glue. Mechanical pressure is applied through insulating members to attain a good bond. Figure 19 shows how glue is set in *edge bonding*. Wood sections several inches wide, from 0.5, to several inches thick, and several feet long, are squeezed between electrodes. Wood slabs 4 × 8 ft can be produced in a processing time of 30 to 60 sec; without dielectric heat it would take several hours. Power requirements cannot be figured easily because of the many variables involved, one of which is the

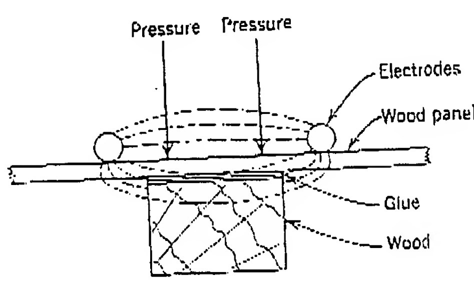


Fig. 18. Wood gluing by dielectric heating.

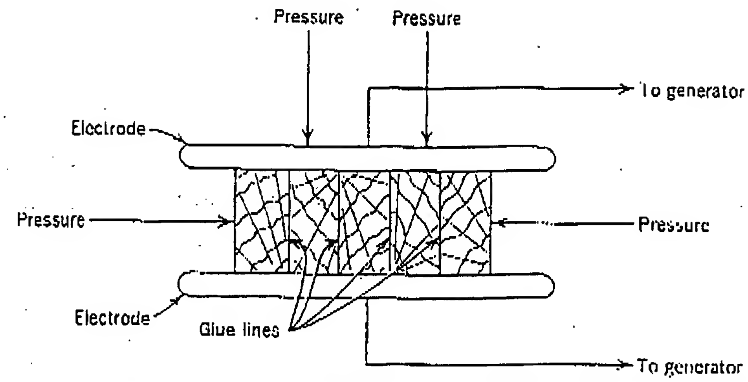


Fig. 19. Edge bonding of wood by dielectric heat.

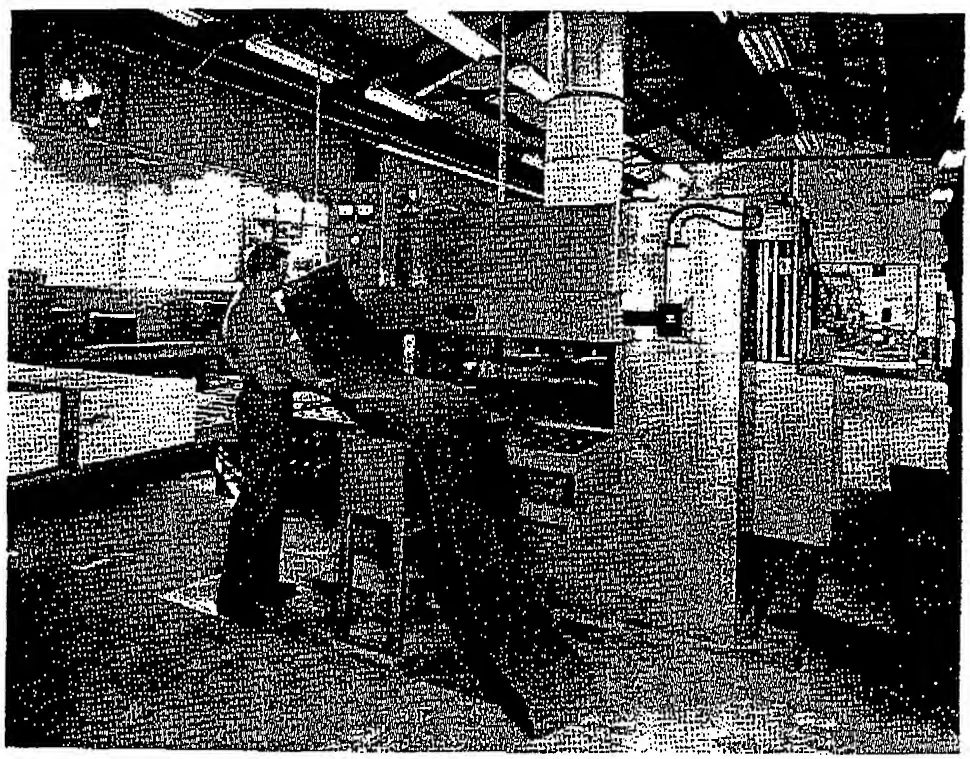


Fig. 20. Paper honeycomb core gluer, expanded-stack hydraulic press, and 40-kW generator automatically squeeze and cure glues, and eject finished compressed honeycomb. Courtesy Faratron.

absorption of heat by the wood from the glue. It is generally estimated that 1 kW will set about 50 to 200 in.[2] of glue line in 1 min.

In a process similar to edge bonding, kraft paper sheets are compressed and glued into a stack. When the glue is cured, the stack is expanded to make honeycomb core stock, to be used for later lamination to sheet materials to produce strong, rigid, lightweight panels. Figure 20 shows a 40-kW stack-gluing dielectric heater and press

unit, and an expanded stack. A 200-lb stack, 10.8 × 18 × 24 in., can be glued up in 7 min on this machine; with conventional heating, a curing time of about 24 hr would be required. See also LAMINATES.

Sealing. Dielectric heating frequently presents a problem of heat flow in reverse to that usually encountered. Although the load is heated uniformly, its exterior is cooler; its outside faces lose heat to the atmosphere and to the electrodes, or belt, or other mechanism that may be in contact with it. In some cases, this heat

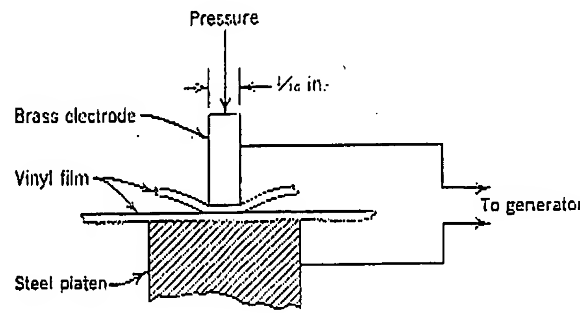


Fig. 21. Arrangement for sealing film.

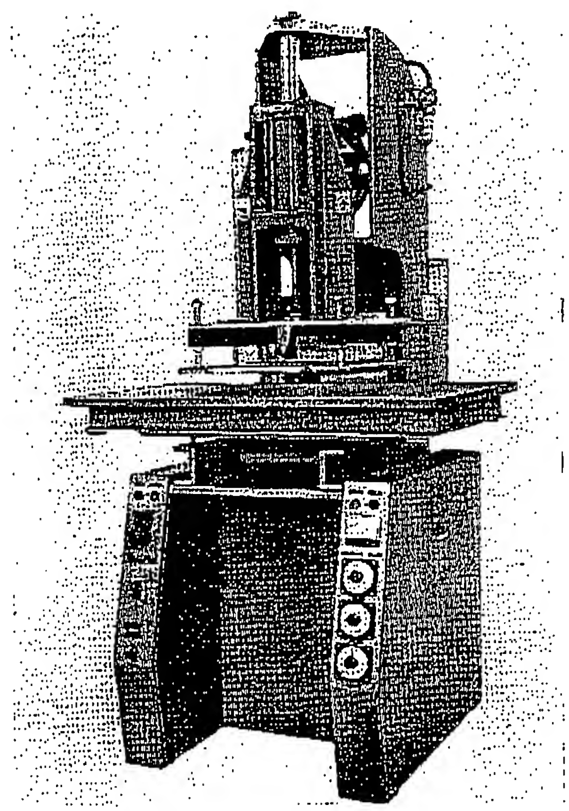


Fig. 22. General-purpose dielectric film sealer, with pneumatically operated press mounted on a 10-kW, 30-Mc/sec generator. Courtesy The Thermatron Company.

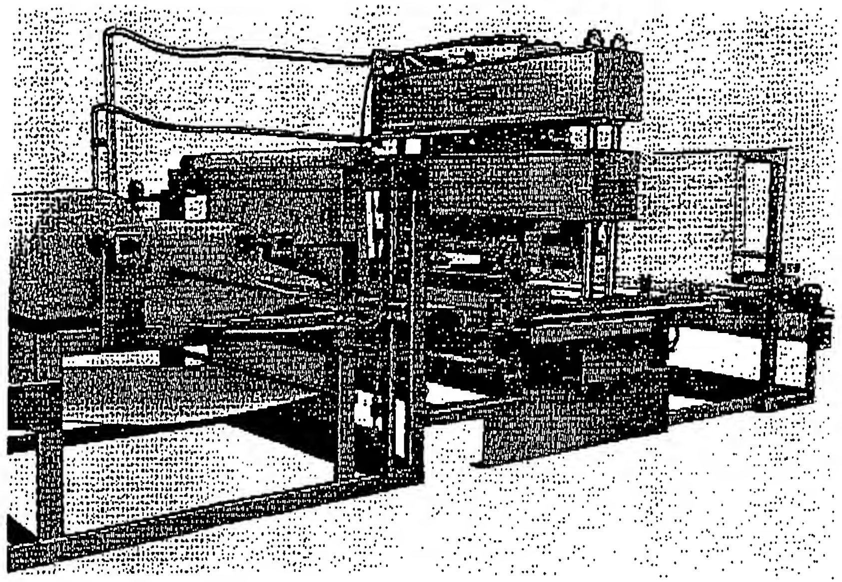


Fig. 23. Automatic dielectric sealer. A web of wadding is fed between two webs of vinyl film through a 75-ton press, which seals the three webs in a quilting pattern. A 35-kW, 30-Mc/sec generator (not shown) is used. Production rate is 24 seals/min. Courtesy The Thermatron Company.

loss aids the process, and in others it must be compensated for. The welding, or sealing, process shown in Figure 21 illustrates both effects. Two pieces of 0.004-in. thick vinyl film are to be sealed together. A metallic electrode, usually of brass, perhaps 1/16-in. thick and several feet long, squeezes the film against the steel bedplate of a pneumatically operated press. High-frequency voltage is applied, causing the plastic to heat and melt. The brass and steel do not get hot under the influence of the high-frequency energy. Since they are in intimate contact with the vinyl film and since the film is very thin, they absorb a good deal of the heat generated in the plastic. To compensate for the loss, several times more heat must be developed in the film than would be needed for melting it. However, after the plastic is melted and the power is turned off, the cool metal electrodes rapidly refreeze the plastic. Without refreezing under pressure, a poor bond would result. An additional advantage is that the outer surfaces of the film can be kept below the melting point, and so maintain their original characteristics. A manually loaded plastic film sealer is pictured in Figure 22, and an automatic machine in Figure 23. Total cycle time (heating and cooling) for these equipments can be a fraction of a second or several seconds, depending on the application. See also WELDING.

Vinyl film and sheet are sealed by high-frequency heating to form a great variety of products, from wallets to swimming pools. Fabrics of cotton, nylon, glass fiber, or other materials, coated or impregnated with heat-sealable materials such as plasticized poly(vinyl chloride) or polyurethan, are sealed to form products requiring greater strength than can be obtained from the unsupported films. A striking example to see is the "air-house," an inflatable structure which typically can be constructed to provide a shelter 60 ft wide, 30 ft high, and hundreds of feet long, and is made almost entirely of dielectrically sealed poly(vinyl chloride)-coated nylon fabric; kept inflated

with small air compressors and held in place with guy wires, it can easily support high wind and snow loads.

A large-scale application for dielectric heat sealing is in the manufacture of the inside door panels for automobiles. The panels are made of a supported or unsupported vinyl top layer, an interlayer of padding, and a bottom layer of paperboard about 0.1 in. thick. For good bonding, the padding may be impregnated with a vinyl or other adhesive, and the board is adhesive-coated.

Polyurethan and vinyl foams may be sealed between vinyl sheets for products such as pillows. Although vinyl does not "weld" to polyurethan, the wanted seal can be obtained because the vinyl sheets will weld to each other through the polyurethan foam if enough pressure is used and if the foam has a low density. As was previously mentioned, mixing poly(vinyl chloride) into the polyurethan will help the sealing process.

An unusual application of dielectric heating is the sealing of a cotton shirt label to a cotton shirt. The label has woven through it a polyester thread that, heated by high-frequency energy, is made to melt and flow into the interstices of the cotton fabric. The mechanical interlocking of the polyester with the cotton textile quite effectively bonds the label to the shirt. Similarly, a strip of nylon film has been used to seal two layers of the cotton fabric tape on zippers.

Many woven and nonwoven thermoplastic fabrics can be dielectrically sealed. Poly(vinylidene chloride) woven fabric has been used for many years in heat-sealed industrial products, as, for example, a fuel filter for automobiles. Dielectric heating equipment has recently been made available to seal some nylon and cotton–polyester textiles.

Microwave Heating. Microwave heating is most used in food processing, but there are some industrial applications and there has been much experimentation for new uses. *Domestic and commercial ovens* are employed for rapid food preparation—many of these contain conventional coils for radiant heaters to brown the food because the microwaves do not heat the outside enough to compensate for surface heat losses. Microwaves are also used for *food processing at the factory level* (6,17). Experiments have been made with *preform heating by microwaves*.

Moisture removal requires much energy, which can be cheaply supplied by conventional methods for most of the drying but removing the last small amount of moisture has usually been costly and space-consuming; microwaves do this efficiently and the equipment requires little space. Photographic film is now partially dried, after development and rinsing, by hot air and squeegee, then finish-dried by microwaves. In film manufacture, microwaves are being used to dry the buildup of emulsion on the edges.

There are other interesting uses: glue is set in the production of multisheet business forms; banks dry the magnetic ink printing on checks; glue is dried on paperboard for cartons; glue for "perfect" bindings (bookbacks glued without sewing) is set; and polyurethan foams are cured (18,19).

Economics

Because dielectric heating is qualitatively so different from all other methods, cost comparisons are usually meaningless. In the limited number of uses where similar results can be obtained by more conventional forms of heating apparatus, di-

electric equipment is generally higher in cost. However, high-frequency units are more efficient as energy converters, putting into the load 50 to 70% of the power-line input, and, unlike ovens, no preheating of the equipment is needed (microwave equipment is far less efficient). Electric power costs will therefore be less than for other types of electric heating; the high efficiency can make it competitive with fossil-fuel heating in some cases. There are other cost factors to be considered: Plant space requirements are low, both for equipment and materials—other treatment methods may use more space-consuming equipment and may require space for materials to "cure" or "set" or "thaw" for hours or days. In some cases plant capacity can be multiplied without space increase by substitution of dielectric heaters for less efficient fossil-fuel ovens. The high efficiency allows the equipment to run cool; it is comfortable to work near and means of removing excess heat are not required. Equipment costs run from approximately $1000/kW for very small units and to about $250/kW for the highest powered machines. The electrodes and materials-handling devices may be inexpensive, or, for complicated processes, they may cost more than the generating equipment itself. Maintenance costs for dielectric heaters are minimal, usually much lower than for other heat sources. Although the dielectric heating machine has unfamiliar high-frequency circuitry, its control and power circuits are relatively unsophisticated; maintenance and trouble-shooting can usually be done by plant electricians or mechanics who have had a little instruction from the equipment manufacturer. Generator parts replacement costs for high-frequency units are around 1–2¢/hr/kW of output power, and about 2–3¢ for microwave equipments. Most electrode systems rarely need service or replacement.

Safety

The dielectric heater can radiate energy which might interfere with aircraft communications, television, or other radio services. To minimize interference, allowable radiation limits and methods of measurement are specified by the Federal Communications Commission's Rules and Regulations, Part 18, for Industrial, Scientific, and Medical Equipment. Compliance with these rules is required for operation of equipment in the United States. These rules permit unlimited radiation on certain very narrow frequency bands, or limited radiation on any other frequency. Equipment for operation on an assigned frequency band requires high-stability circuits for frequency control, and must be designed to prevent radiation of energy at all other frequencies generated internally because all dielectric heaters simultaneously generate their operating frequency and its harmonics. This type of equipment permits use of electrodes unencumbered by shielding, allowing easy access for material handling. However, there are disadvantages: it is more expensive and much larger than unstabilized units; adjustment and maintenance are less simple; in many instances, the allowable frequencies do not fit the needs of the process. Not much stabilized equipment is used in the United States; however, it is used widely in Europe.

For operation outside the assigned bands, radiation is limited by shielding or screening the generating equipment and the electrodes. The shielding may be an integral part of the equipment, or it may be a screened room in which one or more unshielded units are operated. The self-shielded equipment has access doors or hoods for loading materials; for continuous processes, materials are fed through radiation-limiting tunnels to the electrodes. The self-shielding devices reduce accessibility for

materials handling, but do permit operation on the most suitable frequency. The least expensive equipment, and the least restrictive of materials handling at the electrodes, is the unshielded equipment in a screened room. Most plastics-welding equipment (Figs. 22 and 23) is in this class, some plants having a hundred or more units in a screened room; the room entrance may restrict the flow of materials somewhat. Compliance with the Federal Communications Commission's rules must be formally certified; it is usually done by the equipment manufacturer at his own plant for stabilized or self-shielded equipment. Unshielded equipment must be measured for compliance, and rechecked periodically, at its operating location; measurements may be performed and formally certified by an independent consulting engineer, by the equipment manufacturer, or by the user.

Improperly operating microwave equipment may emit concentrated energy beams, exposure to which must be avoided. With properly designed and operating equipment, however, there is no industrial health hazard. The generator is designed so that opening doors or taking off panels will automatically turn off any dangerous voltages. The work applicators are generally guarded to prevent the operators from coming in contact with them. In properly designed equipment there are no lethal voltages on the work applicators that an operator might accidentally touch. Touching an electrode would cause a burn, possibly a severe one, not any worse, but possibly deeper, than that caused by touching any thermally hot object.

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DIELECTRIC PROPERTIES. See ELECTRICAL PROPERTIES

DIELS–ALDER POLYMERIZATION

In the search for new polymers and different polymerization reactions many well-known organic reactions used for the synthesis of small molecules have been investigated as means to build up large molecules. Ideally, the reaction should involve stable, easily purified compounds and should give essentially quantitative yields without side reactions. Whereas few reactions meet all of these requirements, there are many which are suitable and which only recently have been applied to the synthesis of high-molecular-weight polymers.

Many of the numerous variations of the Diels-Alder reaction (also called "diene synthesis" in the European literature) come close to meeting the ideal requirements for a polymer-forming reaction. The Diels-Alder reaction involves the 1,4 addition of a *dienophile* (an unsaturated compound, such as an olefin or an acetylene) to a conjugated *diene* resulting in the formation of a six-membered ring. Equations 1 and 2 give a generalized representation.